Renewable and Sustainable Energy Reviews 15 (2011) 2520–2533

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Analysing future trends of renewable electricity in the EU in a low-carbon context

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ARTICLE INFO

Article history:
Received 18 April 2010
Accepted 27 December 2010

Keywords:
Renewable energy
Electricity
Europe

ABSTRACT

The aim of this paper is to analyse the situation and trends of electricity from renewable energy sources (RES-E) in the EU up to 2030, taking into account several drivers and barriers and different maturity levels for the renewable energy technologies. The methodology is based on the results of simulation models providing insights on future outlooks, complemented with an analysis of regulations and other drivers and barriers. Regarding the most mature renewable electricity technologies, the main drivers will be public policies (carbon prices and support schemes) and the expected up-ward trend in fossil-fuel prices and the main barriers are related to grid access, administrative procedures and the exhaustion of places with the best wind resource. For those already commercial but expensive technologies, the main driver is support schemes (but not carbon prices) allowing the exploitation of the large potential for investment cost reductions. Barriers are mostly related to their high investment costs. Finally, for those technologies which are emerging and immature, further technical improvements as a result of R&D efforts will be needed and they cannot be expected to significantly penetrate the European electricity market until 2030.

Contents

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doi:10.1016/j.rser.2010.12.013

1. Introduction

Electricity generation is a key sector to consider in a policy aimed at mitigation of greenhouse gases, both at the world and EU levels. This is so for several reasons. Although the share of emissions from the power generation sector has been reduced since 1990 in a couple of percentage points, it still accounts for more than one third of total emissions. On the other hand, there is a high perceived feasibility of emissions reductions in this sector, given the existence of comparatively low cost technological alternatives and the possibility to pass the induced costs of mitigation policy into electricity prices. This is related to the traditionally low level of international competition in this sector. Furthermore, since many other sectors (and particularly transport) will increase their use of electricity as energy input (see [1,2]), decarbonization in the power sector gains strategic importance. Several low-carbon technologies are available in the power sector, including renewables, energy efficiency, nuclear, cogeneration and CCS. This paper focuses on electricity from renewable energy sources (RES-E).

The aim of this paper is to analyse the situation and trends of RES-E in the EU up to 2030, taking into account several drivers and barriers. We have chosen 2030 as the timeframe because, with one exception (i.e. [3]), simulations studies mostly refer to this year and because foresights become more difficult and imprecise the more we move into the future.[1] It is assumed that drivers and barriers should be explored in order to identify possible developments of the sector that contribute to its better understanding. However, the aim is not to forecast the diffusion of RES-E in the EU, but to provide some hints on broad but likely trends.

The methodology is based on the results of simulation models providing insights on future outlooks. However, since modelling work cannot include relevant qualitative aspects, we complement this approach with an analysis of regulations and other drivers and barriers. For this, official documents and statistics which allow us to infer likely trends in barriers and drivers are analysed. In addition, three sources of expert opinions on likely technology trends and the evolution of drivers and barriers affecting deployment have been considered: articles in the most important international journals on energy, energy policy and climate policy, general reports and relevant websites, a few expert interviews carried out by the author and the results of several European projects.[2]

The paper is structured as follows. The next section provides an overview of general drivers and barriers to RES-E. Section 3 summarises the results of different model simulations with respect to RES-E in the EU in 2030. A qualitative assessment of the drivers and barriers to RES-E deployment in the EU and their likely trends is provided in Section 4. Section 5 uses the above material to discuss possible trends of these technologies in the future in the EU. Section 6 concludes.

[1] The aim is to keep concentrations of greenhouse gases at a level which avoids exceeding the 2 °C increase in temperatures, which is considered as a safe level to avoid catastrophic impacts from climate change. Therefore, mitigation measures have to be implemented now. A consistent result of modelling work is that delaying action on climate change mitigation will make the 2 °C increase either unattainable or very expensive to reach. This is the main reason why modelling work usually considers the 2030 horizon consistent with the 2 °C increase in 2100 (see [1]).

[2] A literature review was performed by the author for the RECIPE Project on the Economics of Decarbonisation (see [1]).

2. An overview of the general drivers and barriers to RES-E deployment

Several drivers and barriers affect the development and deployment of RES-E. Frequently, though, drivers and barriers are the opposite sides of the same coin. The literature has discussed all these factors, although usually not in an integrated manner. Table 1 provides an overview of all these factors.

In this context, both a systemic and a dynamic perspective are necessary. Regarding the former, several authors have stressed the importance of “systemic barriers” to the removal of existing technologies (see [12–14], among others). It is stressed that lock-in in carbon-intensive technologies is the result of political, regulatory, and social systems that support existing technologies and act as major barriers to the introduction of low-emission technologies in all types of economies.

A dynamic perspective on investment cost aspects is also important. The costs of the technologies can be reduced with R&D investments, economies of scale and learning effects.[3] The extent of these reductions depends on two interrelated aspects: the maturity of the technologies and their level of deployment. Immature technologies profit much from the existence of significant learning effects and R&D investments, which can lead to substantial cost reductions. However, in the absence of policy measures, a vicious cycle is likely: those technologies do not diffuse because their costs are high and they are high because they have not profited from learning effects and dynamic economics of scale which result from diffusion and from R&D investments. Therefore, deployment and R&D policies have a key influence on these costs.

3. RES-E in the EU in 2030: insights from models

3.1. Past and current situation of RES-E in the EU

RES-E has increased in the 1990–2007 period, although at different rates (Fig. 1). Those with the highest increase are also the ones starting from the lowest base (wind, solar and biomass). The greatest absolute and relative increase has been in wind electricity. In turn, the growth rate of hydro is more modest, but its current share is quite significant. RES-E represents 16% of total generation in 2007 versus 12% in 1990. The loss of share in hydro (from 11% to 9.5%) has been more than offset by a greater share of the other RES (from 1% to 6.6%), particularly wind and biomass. The later represent 2.5% and 3.5% of total generation, respectively.

Therefore, in spite of the rise of RES-E, the EU generation mix is currently dominated by fossil fuels. Compared to 1990, fossil-fuel generation has remained constant, although with a greater share of gas and a lower share of coal and nuclear.

3.2. The simulation models[4]

In this section we provide a comparative analysis of the following model simulations regarding RES-E trends up to 2030:

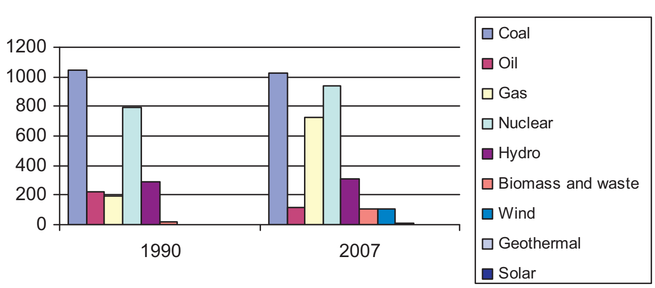
[3] Trends in learning rates will also be affected by the scarcity of some key materials (silicon for PV, steel for wind turbines).

[4] This and the following subsection are based on work carried out by the author in the RECIPE project (see [24]).

Table 1
Factors influencing RES-E deployment.

BARRIER		Description
1. Techno-economic factors.	The double externality problem	(1) Environmental externality: if firms do not have to pay for the damages caused by their GHG emissions, then a low incentive for innovation in low carbon technologies results. (2) Technological externality: spillover effects enabling copying of innovations reduce the gains from innovative activity [4,5]
	Potentials	The availability and quality of the resource, which affects the amount of electricity produced, is location-specific. Therefore, the analysis of country or region-specific RES-E potentials is crucial [6]
	Investment cost trends (learning effects)	Investment costs are currently much higher for renewables than for conventional technologies. With respect to the installed capacity (MW), technologies investment costs are very high for some technologies (solar PV), while they are lower for others (wind). Significant cost reductions are expected for these technologies (see Section 4)
	Variable costs (O&M, fuel prices)	O&M costs vary per renewable technology, but generally represent a very small fraction of total costs and are generally low for RES-E, although not lower than for its conventional competitors (see [7]). Fuel costs are cero for RES-E
	Age of plants	The capital cycle affects the likelihood that conventional technologies are replaced by renewable ones. Since power stations are usually replaced only at the end of their useful life (about 40 years), this creates an important obstacle to capital-intensive RES-E investments
	Grid integration	At high penetration levels the intermittency of some renewables will pose new challenges to the stability, reliability and operation of electricity grids [8]. The additional costs for grid back-up and/or electricity storage and spinning reserve needed to absorb the large-scale grid integration of variable renewables have to be considered [9,10]
2. Legal and administrative barriers		The deployment of renewables faces barriers related to the granting of administrative authorisations or grid access procedures
3. Political factors		RES-E requires targets and support policies (emissions trading schemes (ETS), R&D and deployment support). Stop-and-go RES-E policies create risks for investors and discourage RES-E investments
4. Social acceptability		Lack of social acceptance can discourage RES-E investments. Rejection may take two forms, a "generic" attitude against RES-E or a more localised NIMBY syndrome, related to perceived negative (local) environmental aspects of the technologies
5. Other factors	Subsidies and other advantages to fossil fuels	These discourage technological competition in a levelled playing field
	Lack of information	Lack of information on new technologies may discourage their adoption. The alternatives are not well known and their performance characteristics are compared to the conventional technologies
	Human capital factors	The existence of skilful personnel is highly relevant for the adoption of these technologies. This includes building up local innovation capacity on the back of deployment
	The role of pioneers	The willingness to engage in a new technology facilitates the initial adoption in small niches. This depends on the risk-aversion of individuals and countries [11]

Source: Own elaboration.



Source: [2]. Solar generation has increased from 0 to 4 TWh, Geothermal from 0 to 6 TWh, Wind from 1 to 104 TWh, biomass and waste from 20 to 105 TWh and hydro from 286 to 309 TWh.

Fig. 1. Electricity generation in the EU27 in 1990 and 2007 (TWh). *Source*: Ref. [2]. Solar generation has increased from 0 to 4 TWh, Geothermal from 0 to 6 TWh, Wind from 1 to 104 TWh, biomass and waste from 20 to 105 TWh and hydro from 286 to 309 TWh.

- The POLES model [15].
- The WETO study [16], also based on the POLES world energy sector simulation model.
- The PRIMES model [17].
- The U.S. Energy Information Administration of the Department of Energy [18].
- The World Energy Outlook 2007 [19].
- The World Energy Outlook 2008 [20].
- The World Energy Outlook 2009 [2].
- WITCH [21].
- IMACLIM [22].
- REMIND [23].[5]

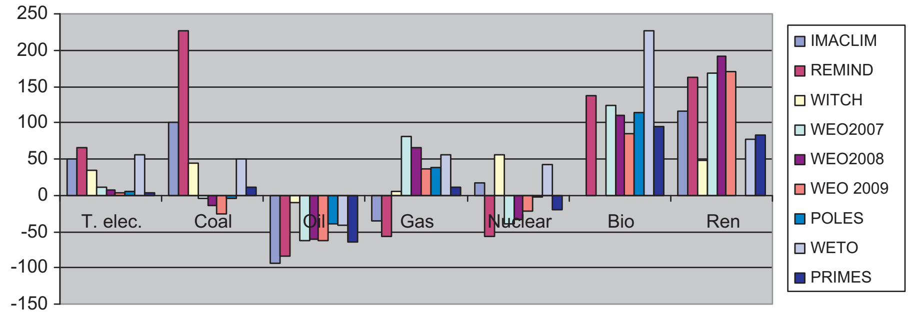
These models will be referred throughout this study as the POLES, PRIMES, WETO, US EIA/DOE, WEO2007, WEO2008, WEO2009, WITCH, REMIND and IMACLIM, respectively.

Two main caveats of this comparative analysis are worth mentioning.[6] First, the results of the models may differ as a result of different assumptions and the use of different databases. A comparative analysis of those assumptions is not provided. Second, data for Europe refers in most cases to the European Union (EU27) (WEO2007, WEO2008, POLES, PRIMES, WITCH, REMIND and IMACLIM), in one case it refers to OCDE-Europe (U.S. EIA/DOE) and in another case to "Europe" (WETO). This certainly limits the comparability of results.

Only five studies provide data with sufficient level of detail for both the reference (business-as-usual) and the policy scenar-

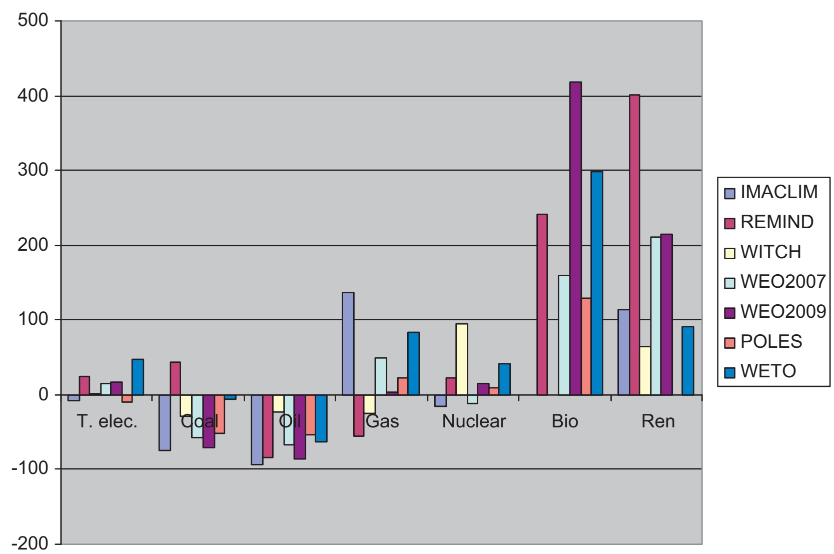
[5] IMACLIM, REMIND and WITCH are three state-of-the-art numerical energy-economy models to analyze economic and technological implications of ambitious climate mitigation policy. These hybrid models are characterized by a combination of a realistic and complete top-down representation of the macro-economic growth process and a technologically explicit bottom-up representation of the energy-system.

[6] In addition, energy models, as any model, have limitations (see [25]).



Source: Own elaboration.
T. Elec = Total electricity generation; bio = biomass; Ren = all other renewables.
* POLES: Biomass and renewables are aggregated.
** No biomass is expected to be deployed in the period in IMACLIM and WITCH in this scenario.
*** In WEO2008 and WEO2009 the base year is 2006 and 2007, respectively.

Fig. 2. Electricity generation trends in 2005–2030 (accumulated % growth). Baseline scenario. *Source*: Own elaboration. T. Elec = total electricity generation; bio = biomass; Ren = all other renewables. *POLES: Biomass and renewables are aggregated. **No biomass is expected to be deployed in the period in IMACLIM and WITCH in this scenario. ***In WEO2008 and WEO2009 the base year is 2006 and 2007, respectively.



Source: Own elaboration.
T. Elec = Total electricity generation; bio = biomass; Ren = all other renewables.
* POLES: Biomass and renewables are aggregated.
** No biomass is expected to be deployed in the period in IMACLIM and WITCH.
*** In WEO2009, bio refers to biomass, solar, geothermal and tide and wave. Ren refers to wind and hydro.

Fig. 3. Electricity generation trends in 2005–2030 (accumulated %). Policy scenario. *Source*: Own elaboration. T. Elec = total electricity generation; bio = biomass; Ren = all other renewables. *POLES: Biomass and renewables are aggregated. **No biomass is expected to be deployed in the period in IMACLIM and WITCH. ***In WEO2009, bio refers to biomass, solar, geothermal and tide and wave. Ren refers to wind and hydro.

ios (i.e., with additional mitigation measures to those already implemented).[7] These models are the WEO2007, WETO, WITCH, REMIND, and IMACLIM.

3.3. Expected RES-E trends in Europe

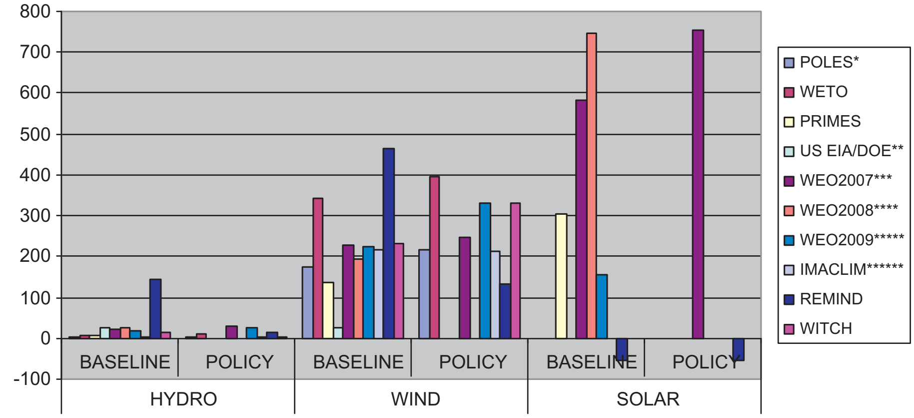
The trends in activity levels up to 2030 can be analysed per model, scenario (baseline and policy scenarios) and technologies.[8]

A comparative analysis of the results of the models is provided in Figs. 2–4. Significant increases in the baseline scenario for biomass and other renewables, substantial reductions in oil and mixed results for coal, gas and, especially, nuclear are expected. Within other RES, impressive growth rates are expected for wind and solar and, where data is available, for geothermal and tidal and wave, whereas biomass and wastes have lower growth rates, although still higher than for non-RES. In spite of these high growth rates, renewables (with the exception of wind) will have a low share because they start from a very low base.

The results for the policy scenario consistently show that, with respect to the baseline scenario, a stringent climate policy would encourage the uptake of biomass and other renewables and discourage investments in other technologies (coal).

[7] For example, the EU ETS is part of the reference scenario (because it is already implemented), but more ambitious RES-E policies than those already existing are part of the policy scenario.

[8] Primary energy has been chosen because this facilitates the comparability of results between models.



Source: Own elaboration.
* Includes all renewables except hydro.
** All RES
*** 2010 data calculated with lineal interpolation (2005 and 2015)
****2010 data calculated with lineal interpolation (2006 and 2015)
*****2010 data calculated with lineal interpolation (2007 and 2015)
****** Includes wind and solar.

Fig. 4. RES-E generation. Accumulated percentage variation in 2010–2030. *Source*: Own elaboration. *Includes all renewables except hydro. **All RES ***2010 data calculated with lineal interpolation (2005 and 2015) ****2010 data calculated with lineal interpolation (2006 and 2015). *****2010 data calculated with lineal interpolation (2007 and 2015). ****** Includes wind and solar.

Table 2
Share of different electricity generation technologies in total generation in 2030 in the EU (%).

	2005	2030	
		Reference scenario	APS
Total generation	100	100	100
Coal	30.6	24.8	11.8
Oil	4.2	1.3	1.4
Gas	20.3	30.9	25.1
Nuclear	30.5	13.9	23.4
Hydro	9.3	9.8	11.9
Biomass and wastes	2.6	4.9	6.6
Wind	2.4	12.5	16.9
Geothermal	0.2	0.3	0.5
Solar	0.1	1.3	2.0
Tide and wave	0.03	0.2	0.5
TOTAL RES-E	14.63	29	38.4
TOTAL RES-E (excl. Hydro)	5.33	19.2	26.5

Source: Ref. [19].

Fig. 4 illustrates the trends of other renewable electricity technologies. Most models expect a substantial increase in wind in 2010–2030 in the *baseline scenarios*. A more stringent climate policy would provide a large boost to wind. *Hydro* would experience very modest increases in both the baseline and policy scenarios. Finally, concerning *solar*, with the exception of REMIND, the models show a three to eightfold increase. More stringent emission targets may not lead to a greater deployment of this technology: one study expects a higher deployment in the policy scenario with respect to the baseline (WEO2007) and, another, a similar level of deployment (REMIND).

The expected share of RES-E in two scenarios (reference scenario and an scenario compatible with 450 ppm CO_2 emissions concentration levels, so called Alternative Policy Scenario or APS) are provided in [19], based on model simulations (Table 2). It is shown that, even in a reference scenario and without including large hydro, the share of RES-E would not be negligible. The share would be no lower than one fifth of total generation and no greater than two fifths. Hydro and, especially, wind would represent the largest shares.

While modelling work provides useful insights, it cannot capture all relevant aspects affecting the choice of renewable electricity technologies. The challenges to RES-E deployment under a 450 ppm scenario are manifold and cannot be grasped by models. They include non-cost barriers (i.e., administrative procedures, grid access and social acceptability issues), investor risks under different support schemes, fuel price risks, the complementarity of different technologies and the availability of investment funds, industrial capacity and materials to support significant increases in RES-E. Most of these aspects are dealt with in the next sections.

4. Policy and techno-economic issues affecting RES-E deployment in the EU: current situation and expected trends

4.1. Techno-economic aspects: current situation and expected trends

Obviously, a discussion on the maturity levels and investment costs of renewable electricity technologies transcends the EU perspective, although it certainly has implications for the deployment of these technologies in the EU.

4.1.1. Current maturity levels

Technologies can be classified along a continuum from invention to mass-market diffusion (i.e., from the more immature to the more mature, already commercialised). There are several classifications on the level of maturity of technologies. IEA [26] considers three main stages (prototype and demonstration, as with enhanced geothermal systems, EGS), market niches (high cost-gap technologies renewables, as with solar PV) and mass markets (fully mature technologies, such as hydro). Between the second and the third stages there are low cost-gap technologies, such as wind on-shore. A critical stage is the so-called valley of death [26,27], which refers

Table 3
Current and expected costs of electricity generation technologies.

Energy source	Power generation technology	Production costs of electricity (€2005/MWh)		
		State of the art 2007[a]	Projection for 2030 (moderate fossil fuel price scenario)[b]	Projection for 2030 (high fossil fuel price scenario)[c]
Natural gas	Open cycle gas turbine	65–75	90–100	160–165
	Combined cycle gas turbine	50–60	70–80	115–125
Oil	Internal combustion diesel engine	100–125	140–160	230–250
	Combined cycle oil-fired turbine	95–105	125–135	200–205
Coal	Pulverized coal combustion	40–50	65–80	85–100
	Circulating fluidised bed combustion	45–55	75–85	95–100
	Integrated gasification combined cycle	45–55	70–80	85–95
Nuclear	Fission	50–85	45–80	55–85
Biomass	Solid biomass	80–195	85–205	95–220
	Biogas	55–215	50–190	50–190
Wind	On-shore	75–110	50–85	50–85
	Off-shore	85–140	50–95	50–85
Hydro	Large	35–145	30–130	30–130
	Small	60–185	50–145	50–145
Solar	Photovoltaic	520–880	170–300	170–300
	Concentrating solar power (CSP)	170–250	100–140	120–160

Source: Ref. [17].
[a] Oil price in 2007: (54.5$/barrel). Oil prices in 2005$.
[b] Fuel prices in 2030 (moderate fossil fuel scenario) = 63$/barrel.
[c] Fuel prices in 2030 (high fossil fuel scenario) = 119$/barrel.

to the fact that it is difficult for some mature technologies to reach commercialization due to their high costs.[9]

4.1.2. Current costs

There are several estimates of the costs of the technologies, which are under continual review by governments and international agencies (see, among others [3,17,18,28]).[10] No two studies agree precisely, and most admit to appreciable uncertainties [29].[11] However, there are several common aspects: (1) compared to their fossil-fuel counterparts, renewable energy technologies generally have higher total costs (inclusive of investment, operation and maintenance and fuel costs). (2) The higher capital intensity of renewable electricity technologies (wind and hydro) determines their higher total costs (in spite of their non-existent fuel cost). (3) Within renewables, there are also significant differences. Hydro, biogas and wind on-shore tend to be on the lower part of the cost range, whereas solar technologies are relatively expensive. (4) There are also significant variations within a technology, depending on the different resource potentials of the location of the power plant (in the case of renewables) (Table 3).

4.1.3. Resource potentials

Obviously, a comprehensive investigation of the future of RES-E development in Europe requires an analysis of renewable potentials with respect to other regions in the world. Several EU-funded projects have been dedicated to this task, including GREEN-X, OPTRES, FORRES 2020, GREENNET and FUTURES-E. They all show that, although a fraction of this potential has already been exploited in Europe (especially with respect to wind and hydro), there is still significant potential in virtually all renewable energy technologies, with the exception of large hydro and geothermal (see [6,30]). Per country, Germany, France, Spain and the U.K. held the greatest potential in absolute terms in 2004 in the EU. Some countries had already exploited a significant part of their total potential by 2005 (Austria, Finland, Slovakia, Slovenia and Sweden).

Fig. 5 shows that significant unexploited potentials in RES-E exist in the EU and the world (column on "additional potentials").[12] These additional potentials are greatest in the cases of wind and solid biomass. In contrast, the additional potentials to be exploited in hydro in the EU are only a small fraction of the total potentials. This is in contrast to the rest of the world, where there is still significant additional potential. The total additional potential (1294 TWh) is evenly distributed between countries according to their surface area. Four countries (France, United Kingdom, Germany and Spain) account for 60% of this additional potential [26].

A relevant comparison is between the potential of each renewable electricity technology and their respective costs (i.e., compare Fig. 5 and Table 3). This shows that some renewable technologies have a large additional potential at medium to low costs in the EU (wind and biomass), whereas solar (PV and thermoelectric) have medium potentials at relatively high costs.

4.1.4. Fuel prices

Fuel prices are a main variable influencing cost trends of conventional electricity generation technologies and, thus, the competitiveness of their renewable counterparts, which are fuel free. Higher fuel prices lead to a greater competitiveness of renewable technologies, and the advancement along their learning curves (Table 3, compare the last two columns), although this would not make the most expensive renewables (i.e., solar PV) competitive. There is a high concern in Europe on the possible evolution of those costs and on the security of supply of fossil-fuels themselves. While

[9] Ref. [3] considers basic science, applied R&D, demonstration, deployment and commercialisation stages. Ref. [29] classifies renewable technologies in two categories: already mature (on-shore wind, hydro, biomass co-firing, tidal barrages, geothermal and off-grid PV) and emerging now until 2025 (offshore wind, solar thermoelectric and energy from waves and tidal sources).

[10] For an overview of those costs, see [24].

[11] Estimates vary with: (1) the world prices of oil, gas and coal; (2) assumptions as to rates of innovation; (3) location. Costs differ within a country, and even more between countries; (4) the constraints facing a country: the availability of land for onshore wind local planning requirements, and so forth; (5) the weights of each technology in the supply mix – how much emphasis is given to nuclear power, wind, biomass, distributed generation, and so forth [29].

[12] Realisable mid-term potentials describe the maximal achievable potential assuming that all existing barriers can be overcome and all driving forces are active. The total and additional mid-term potentials for electricity generation refer to the year 2020 [6].

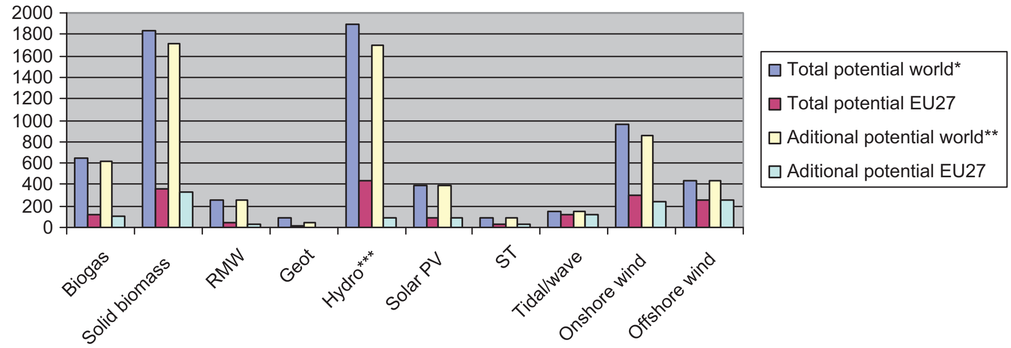


Fig. 5. Total and additional renewable electricity potentials in the EU and the world (TWh, 2005). *Source*: Own elaboration from [26]. RMW = renewable municipal waste; ST = thermoelectric. *Total realisable mid-term generation potentials (in TWh). World includes OECD and BRICs. **Additional realisable mid-term generation potentials (TWh). ***The total realisable potential for hydro in the world is 4041 TWh.

Table 4
Expected future learning rates.

Technology	Learning rate [3]	Learning rate [17]
On-shore wind	7%	8%
Off-shore wind	9%	8%
Solar PV	18%	23%
Concentrated solar thermal	10%	10%
Biomass integrated gasifier/combined cycle (BIG/CC)	5%	12% (biomass combustion steam cycle)
Biogas	NA	12.5%
Large hydro	NA	−0.5% per year
Small hydro	NA	−1.2% per year

Source: Refs. [3,17].

it is very difficult to predict the evolution of coal, gas and uranium prices,[13] they are likely to increase in the future.[14]

4.1.5. Expected cost and technological trends (learning rates)

Increased deployment and R&D support is expected to reduce the investment costs of renewable technologies by 2030,[15] although they will still be above their fossil-fuel competitors [3,18,28].

Table 4 shows the expected learning rates for different renewable electricity technologies. Their potential for cost reductions is significant.[16] Those costs reductions would result in low-carbon technologies approaching the costs of the fossil-fuel technologies. Thus, technological advancements and cost reductions, whether as a result of learning or R&D investments, are a crucial driver of RES-E deployment. Using the ADMIRE-REBUS simulation model, [31] show that the rates of deployment of offshore wind energy and biomass gasification in Europe greatly depend on their technological development.[17]

4.1.6. Age of plants (capital cycle)

Slow capital stock turnover is an important factor limiting the rate of diffusion of renewable electricity technologies. But it can also provide a window of opportunity for these technologies. Indeed, several studies suggest that the next few decades will see substantial reinvestment demand in the power plant fleet, which offers potential for new, and cleaner, power plant lines and technologies, including renewables.

In OECD+ countries (which include the OECD and non-OECD EU countries), the capital stock is ageing in the power sector: 40% of the plant stock is now over 30 years old and most importantly, over half of coal-fired capacity is older than 30 years [20].[18] Ref. [33] estimates that between 600 and 700 GW new coal capacity will be needed till 2035, given the replacement of 330 GW old power plants. Kavouridisa and Koukouzas [34] argue that one of the future challenges that the EU energy market faces is precisely the replacement of ageing power plants.[19] An analysis of an inventory of the 20,000 thermal and nuclear plants included in the PRIMES model shows that the average age of thermal and nuclear plants operating in 2006 was roughly 23 years. About 15% of currently operating plants are more than 35 years old. From the 1990s the power sector displays a deceleration of investments in new power plants, despite increasing electricity demand [17].

4.1.7. Grid integration

Grid integration issues, intermittency, grid balancing and reliability pose additional challenges for RES-E in the EU [35]. Particularly, grid access has been pointed out as a key barrier to the deployment of RES-E in some countries (see, for example [12], for the case of Spain and [53] for a comparative analysis of Germany, Spain and the U.K.). Based on a stakeholder consultation carried out in the EU-funded OPTRES project, five grid-related problems

[13] The relevant price trends are those of gas, coal and uranium, which are the main fossil-fuels used to produce electricity in the EU. The use of oil is very limited in this regard (with the exception of Italy and Greece, where it represents 15% and 16% of the electricity mix, respectively).

[14] The average IEA crude oil import price is assumed in the IEA [20] Reference Scenario to reach $122 per barrel in real year-2007 dollars in 2030, up from $100 in mid-September 2008. Since natural gas prices have remained strongly linked to oil prices, they are expected to increase to the same extent. International coal prices have surged in recent years. The average price of coal imported by OECD countries jumped from $42 per ton in 2003 to $73 in 2007 (in year-2007 dollars) and soared to well over $100 in the first half of 2008. Coal prices are assumed to settle at around $120 per ton in real terms in 2010. Thereafter, prices are assumed to remain flat through to 2015 and then to fall back slightly to $110 in 2030.

[15] Investment costs are endogenous to the existence of public policies which allow renewables to advance along their learning curves through increased diffusion. They also depend on R&D investments leading to improvements and cost reductions in those technologies.

[16] Different data sources also show that there have been significant costs reductions for renewable technologies in the past [32].

[17] In contrast, the diffusion of wind onshore does not greatly depend on further cost reductions, but on the remaining potential available on attractive sites. In the case of PV, the impact of endogenous learning is limited because over 90% of all PV capacity is installed outside the EU-25.

[18] Nevertheless, many plants last much longer than their nominal lifetimes, often an accounting convenience, as [39] explain: "For instance, regulated electric utilities were allowed to pay back the capital costs of a plant over some pre-determined lifetime, which regulators generally set at 20–40 years. But a plant at the end of the payback period is not necessarily any more ready for retirement than a house with a paid-off mortgage would be".

[19] Based on the Prognos database, they show that, over 200 GW of replacement capacity must be built by 2020 in the EU, along with more than 100 GW of new power plant capacity, in order to cover the demand.

have been identified: (1) insufficient availability of grid capacity; (2) lack of transparency of the procedure of grid connection is not fully transparent; (3) objectiveness is not fully guaranteed; 4) Costs of grid connection; (4) long lead times to obtain grid connection authorisation [36].

The EU-funded project GreenNet suggest several policy measures to enable large scale grid integration of RES-E into the European electricity systems: implementation of correct unbundling, setting up markets in system operation to mitigate intermittency risk of renewables generation and consideration of the grid operatorsĭ point of view [37]. Since grid integration of intermittent renewables (wind, solar) substantially increases system costs [38], greater interconnection capacity in the EU has an important role to play to mitigate surplus or deficit wind production [1] propose the following options for mitigating the intermittency problem of renewables: (1) dispatchable backup capacities, e.g. gas turbines, (2) storage systems, (3) large scale grid-integration to even out fluctuations across regions, e.g. by establishing a trans-continental super-grid, and (4) demand side management (smart grids).

4.2. RES-E support in the EU

4.2.1. EU-level targets and instruments

After the approval of the so-called Climate Change and Energy package, targets were set for 2020. GHG emissions will have to be reduced by 20% with respect to 1990 levels, renewables will have to contribute 20% to gross energy consumption in the EU, energy efficiency should improve by 20 percentage points and the share of biofuels in transport will have to be 10% of energy consumption. The 20% RES in final energy consumption is included in a new RES Directive (28/2009/EC), which replaces the previous renewable electricity Directive (Directive 77/2001/EC). This target includes the electricity, heat and transport sectors combined. Since the penetration of renewables in electricity is easier than in the other two,[20] it is expected that its share will be higher than 20% (35%, according to calculations made by [40]), in order to achieve that target cost-effectively. The new RES Directive does not establish a harmonised, EU-wide instrument to promote RES and continues to leave the decision on which support scheme to apply in the hands of Member States.

In addition, a key policy to reach the GHG emissions reduction which also affects the deployment of RES-E is the EU ETS. However, many energy technologies become competitive at carbon prices higher than 15–20€/ton CO_2 (e.g. offshore wind over €35/ton CO_2, CCS over €70–90/ton CO_2). Within the EU ETS 300 million allowances have been allocated to large-scale demonstration projects for CCS and innovative renewables. At the current market price of CO_2 (approx. 15€/ton) this would represent 4.5B€.

On the technology-policy front, available financing instruments for R&D include RTD Programmes (national and EU), innovation programmes, debt based financing, venture capital funds, infrastructure funds and market-based instruments. However, no single R&D European programme on renewable energy technologies currently exists. EU action is, therefore, called for to bring coordination and synergies.

The European Council confirmed in March 2009 the need for a substantial increase of private and public energy-related research, development and demonstration (RDD) compared to current levels, working towards at least a doubling of global energy-related RDD by 2012 and increasing it to four times its current level by 2020 [41].

There is an EU-wide strategy/initiative, the European Strategic Energy Technology Plan (SET-Plan), which was adopted as part of the Energy and Climate Package and which aims to accelerate the development of low-carbon technologies, including RES-E.[21] The SET Plan aims to move away from the current paradigm of financing individual projects to one of co-investing in programmes. It sets out a future model for pan-European energy research cooperation based on the effective combination of public resources and the creation of flexible Public-Private Partnerships with industry [41].

The estimated investment needed in the next 10 years in order to effectively advance the actions proposed under the SET-Plan is 5.5 billion € (B€) for wind and 16 B€ for solar. This compares to approximately 850 M€ of investment in 2007 (380 M€ in wind and 470 M€ in solar), of which 60% is corporate RDD investment and the rest are public funds (EU and Member States) [41].

4.2.2. RES-E support: instruments in the Member States

By putting a price on CO_2 emissions, the EU ETS increases the competitive position of renewables versus their fossil-fuel counterparts. Table 5 illustrates the impact of carbon prices on the costs of the different electricity generation technologies. The costs per unit of energy are shown for each technology relative to those of the fossil fuels they would displace, the so called “marker” technology. The marker technologies for electricity generation are coal and gas. It is shown that, in the absence of a carbon price, the costs of the low-carbon technologies are above the costs of the conventional technology. A moderate carbon price (150£/ton of carbon) makes electricity generation from wind (on-shore and off-shore) and biomass competitive with the marker (conventional) technology, although the most expensive renewables (solar) would still not be competitive.

However, the carbon price in the EU ETS has been relatively low and volatile in the past as a result of several factors (see [42]), providing a limited incentive to RES-E investments. The EU ETS is here to stay, at least until 2020, although it is less certain whether its design elements (stringency of targets and allocation method, among others) will be more favourable to renewables in the future [43]. Although increasing, the expected level of carbon prices in the future will remain at moderate levels.[22]

In addition, MS grant support for specific renewable electricity technologies in the form of R&D and deployment support.

The failure to reach a globally binding agreement regarding Greenhouse Gas emissions reductions in Copenhagen in December 2009 has increased the already very important role of domestic measures to reduce emissions, including RES-E promotion. A wide array of direct support schemes for RES-E deployment is currently being applied by the Member States.[23] Deployment support has traditionally been based on three main (primary) mechanisms: feed-in tariffs (FITs), quota systems with tradable green certificates (TGCs) and bidding/tendering systems. These have been supplemented by other complementary instruments (investment subsidies, fiscal and financial incentives and green pricing). Countries usually apply one (or, at most, two) of the schemes in the first group. This

[20] This is so given the comparatively lower costs of RES-E, the availability of a portfolio of relatively less expensive renewable energy technologies and the domestic character of the industry (i.e., very small international competition).

[21] The key technologies/sectors identified in the SET Plan were hydrogen and fuel cells; wind, solar (photovoltaics and concentrated solar power), biofuel, smart grids, carbon capture and storage, nuclear fusion and nuclear fission (Generation IV).

[22] According to the most recent survey of the carbon market (carried out among 3319 public and private sector experts), a CO_2 price between 15 and 20€ is expected in 2010 (European market) and 30€ and 50€ in 2020 (world market). The average expected CO_2 price in 2020 will be 35€. See [44].

[23] It is beyond the scope and length of this paper to provide a description of all these instruments. See [45,36] for details.

Table 5
Impact of carbon prices on the competitive position of electricity generation technologies in 2030 (£pence/kWh).

Low carbon technology	Marker technology	Cost of marker	Cost of marker + carbon price	Cost of low-carbon technology
Electricity from gas with CCS	NG or coal	2.1	5.6	4.5
Electricity from coal with CCS	NG or coal	2.1	5.6	3.8
Nuclear power	NG or coal	2.1	5.6	3.5
Electricity from energy crops	NG or coal	2.1	5.6	4.8
Electricity from organic wastes	NG or coal	2.1	5.6	4.1
Onshore wind	NG or coal	2.1	5.6	3.3
Offshore wind	NG or coal	2.1	5.6	4.5
Solar thermal (sunny regions)	NG or coal	2.1	5.6	8.8
PV: distribted generatn (sunny regions)	NG or coal	2.1	5.6	9.0

Source: Ref. [29]. Crude oil price: $30 per barrel. Industrial price of natural gas: £2/GJ. Assumed carbon price: 150£/ton C. NG = natural gas.

Table 6
Current primary schemes to promote RES-E in the Member States.

	FIT	Quota with TGCs	Bidding/tendering	Investment subsidies, soft loans	Tax exemptions and rebates
Austria	×				
Belgium		×		×	
Bulgaria	×			×	
Cyprus	×			×	
Czech Rep.	×			×	
Denmark	×		×	×	
Estonia	×				
Finland	×				×
France	×		×		
Germany	×			×	
Greece	×			×	×
Hungary	×				
Ireland	×				
Italy	× (PV)	× (except PV)			
Latvia	×				
Lithuania	×				
Luxembourg	×			×	
Malta	×			×	
The Netherlands	×				×
Poland		×			×
Portugal	×			×	×
Romania		×			
Slovenia	×			×	
Slovakia	×			×	×
Spain	×			×	
Sweden		×			
United Kingdom		×		×	×

Source: Own elaboration from [26,40,46].

is complemented by a combination of measures pertaining to the second group. Instruments may be differentiated per technology. All in all, the FIT scheme has been the dominant one (Table 6).

In addition to the EU and national levels, the regional (and sometimes even the local) level is important in this context, because they may implement additional policies for RES-E (for example, investment subsidies in several regions in Spain). However, a complete analysis of these instruments at regional and local levels is non-existent, because it is truly complicated.

In theory, FITs can be a relatively effective instrument, but if support is set at a high level, they can also be expensive. By setting the quota and allowing trading of TGCs, TGC can be expected to be a cost-effective instrument to achieve a pre-defined level of RES-E penetration. By introducing competition between generators, bidding schemes could be expected to encourage RES-E at low costs. In practice, however, FITs have proven to be effective at relatively low costs compared to other instruments, at least for wind energy promotion (see [36,46]).[24] This is due to the lower risks for investors under FITs, who know in advance the amount of remuneration they will receive, in contrast to TGCs, where uncertain and volatile TGC prices involve a risk premium which increases the costs of financing RES-E projects.[25] In turn, bidding schemes have proven ineffective, since the low level of support discourages investors to finally carry out their projects.[26]

On the other hand, the success of RES-E support schemes probably depends more on their design elements than on the instrument chosen [26], i.e., a FIT, bidding, or quota with TGCs can work well or not depending on how they are designed. Ragwitz et al. [36] show that several design elements can/should be included in FITs and TGCs to make an instrument more successful with respect to the effectiveness and cost-effectiveness criteria.

4.2.3. Expected policy trends

The three types of instruments which are highly relevant for RES-E (ETS, deployment and R&D support) will continue to be

[24] These authors comparatively assess the effectiveness and efficiency of support schemes in the EU through two indicators: Effectiveness is defined as the ability to deliver an increase of the share of renewable electricity consumed) and efficiency is defined as the comparison of the total amount of support received and the generation cost.

[25] See [47] for the U.K. case. In Sweden, TGC prices have experienced ups and downs in 2008 between 150 and 250 SEK (see [48]).

[26] It is beyond the scope and length of this paper to provide a detailed assessment of all these instruments. See [45,26,36] for further details.

applied in the EU, with different degrees of relevance for different technologies according to their level of maturity and costs.

The EU ETS will continue to affect the most mature renewables. Electric utilities now face and will continue to face the cost of CO_2 emissions as another input cost. But, at least in the short term, and given their cost difference with respect to conventional electricity (even after the internalisation of CO_2 prices in generation costs) renewable-specific support measures will continue to be applied. The underlying problem is that, as shown above, carbon policies may be relatively ineffective (yet necessary) to tackle the technological externality,[27] i.e., a carbon price is not sufficient to encourage the development or uptake of technologies which are either immature (EGS) and thus need to go through the demonstration stage or are at or nearly at a commercial stage but are currently very expensive even though they have a large cost-reduction potential (solar PV).[28]

Complementary instruments will continue to be needed to address the "technological externality" and facilitate that those technologies reach the "break-even" point given by the carbon price, in which case those technology-specific instruments will no longer be needed and the EU ETS carbon price will be sufficient to boost the mature renewable technologies in the future (which might be immature today).

Furthermore, in addition to the aforementioned combination of instruments, other measures tackling the non-economic barriers to the development and uptake of low-carbon mitigation technologies should be implemented, particularly administrative procedures and grid access. The RES Directive provides some requirements in this regard.

One major issue is whether a uniform, harmonised RES-E support scheme will be applied in the EU. At least until 2020, countries will continue to use their own support schemes.[29] In general, the trend at the EU level has been and will be towards a greater cooperation/collaboration between Member States regarding the fine-tuning of their promotion schemes. A natural convergence towards similar design elements applied in either FITs or TGCs can be expected. No change of scheme has taken place in the last 5 years (with the exception of Ireland) and no shift to a different support scheme is expected in Member States.[30]

On the other hand, ensuring the stability of support schemes is a particularly important issue. Given the dependence of the competitiveness of these technologies on support schemes and their capital intensity, a changing regulatory framework is a significant source of uncertainty and risk. Higher risk premiums increase the cost of financing by lending institutions and make investments more expensive. Therefore, stability of support schemes for low-carbon technologies is an important condition for their effectiveness, but also for their cost-effectiveness. By setting compulsory targets for 2020, the RES Directive is a step in this direction. A follow-up Directive can be expected in the future with targets for 2030 or 2050.

4.3. Other factors

Finally, other factors discussed in Section 2 are likely to affect RES-E investments in Europe. Administrative procedures might be a key barrier. Although the RES Directive requires that some steps be taken to remove this barrier, it has been there for several years. Therefore, it will continue to be a barrier, at least in the short to medium term.

Some studies have focused on this issue. The EU-funded ADMIRE-REBUS project compared the lead times to renewable electricity technologies caused by administrative procedures, showing that they could be a main barrier for some technologies (i.e., small hydro and wind) and countries (Greece) [51]. The EU-funded OPTRES project [52] carried out a stakeholder consultation on the administrative and other barriers that project developers and investors indicated to encounter when installing new capacities. The administrative barriers identified can be classified in the following categories: (1) the high number of authorities involved; (2) lack of co-ordination between different authorities; (3) long lead-times to obtain necessary permits; (4) RES insufficiently taken into account in spatial planning; (5) low awareness of benefits of RES at local and regional authorities. The perception of administrative barriers is greatest for large hydro, followed by small hydro and wind on-shore. This is perceived as a major barrier to RES-E in Estonia, Poland and Finland and a low barrier in many countries, but especially in Portugal, Latvia, France, Austria and Spain. Finally, the results of the PROGRESS stakeholder consultation show that the number of authorities involved to obtain building permits is 9.5 on average. A lack of time limit was identified as a main problem, especially in some countries. Although 61% of the respondents judge the existing licensing procedures as clear and well established, the lead time for authorisation procedures remains too lengthy in most cases. Most of the time-consuming process is in general needed by the Environmental Impact Assessment and the lead time for grid connection [54].

Public acceptability may also be a relevant driver or barrier. This can be interpreted in two ways. A general one is the attitude towards RES-E by the population. The last edition of the EUROBAROMETER [55] shows that 80% and 71% of EU citizens are "very positive" about the use of solar and wind energy in their country, respectively. Hydro is supported by 65%, ocean energy by 60% and biomass by 55%. The fossil-fuel alternatives are less acceptable.[31] A metaanalysis of the social acceptance of recent European RES-E projects reveals that widespread support for RES exists (see [56]).

Public acceptability is also related to local impacts of RES-E deployment and the NIMBY syndrome. The EU-funded research project EURERDEL already showed that public acceptance was one of the key impeding factors for some renewables (e.g. wind or biomass) in relation to land change issues, landscape pollution, reduced comfort and distrust towards unknown technologies [57].[32] Some authors report some local rejection to the sitting of wind farms in the U.K. and France (see [56,58]) and some places in Spain [59]) due to the negative environmental impacts (visual impact, soil occupancy and noise). Increasing levels of penetration of wind energy and concentration of wind farms in specific locations may reduce the generally high social acceptability for these technologies in the EU in the future.

[27] The economic rationale for the public promotion of technological change in the climate mitigation realm is related to the aforementioned "double externality problem" [4,5,49].

[28] For immature technologies the insufficiency of a carbon price to encourage low-carbon technology investments occurs even if this price is high and stable. Low or volatile carbon prices would affect both mature and immature technologies. A high carbon tax or a sufficiently high carbon price in an ETS might be difficult to reach due to political economy reasons [50], or the price could be too volatile (in an ETS).

[29] This was the initial aim of the European Commission in the late 1990s. However, later on (in 2005 and 2008) the Commission stated that it was not the time to propose a harmonised RES-E support scheme. By allowing trade of surplus/deficits of RES-E at the government (but not at the company) level, the current RES Directive has been perceived by some to go in the direction of implementing an EU-wide TGC scheme [53].

[30] There have been some major changes in RES-E promotion policy from FITs to TGCs and some shifts from tendering bidding to TGCs (U.K.) and FITs (Ireland). Ref. [46] shows how these instruments have evolved in the EU in the past.

[31] Gas is supported by 42%, oil by 27%, coal by 26% and nuclear power by just 20%.

[32] Note that lack of public acceptance (including also decision makers) results in smaller demand for such technologies and slower speed of reaching their technological maturity.

Table 7
Summarising the main drivers and barriers for each mitigation option.

Mitigation option	Main drivers/advantages	Main barriers/drawbacks
Biomass	- Supply push: A wide range of conversion technologies is under continuous development - Cost reductions expected: technical learning, capital/labour substitution and economies of scale in larger commercial plants	- Fuel costs are not cero - Logistics (fuel provision) - Lower energy density of feedstocks makes collection, transport, storage and handling more costly per unit of energy - Competing uses for land and water.
Hydropower	- Peak loads in electricity demand can be met in hydro reservoirs (storage) - Multiple benefits (including irrigation and flood control) - Considerable technoeconomic potential in small hydro	- Public opposition (environmental and social impacts) - Longer administrative procedures - Potential exhausted in many places - Back-up capacity for periods of low rainfall - Competition for water and land resources
Wind	- Large unexploited potential - Increased technological efficiencies (capture of lower wind-speeds) - Relatively fast installation (after permitting process) - Critical mass: an international industry has been created *Onshore versus offshore*: - Drawbacks of off-shore: It is about 50% more expensive than onshore wind installations. Investment and O&M costs are greater [3]. Difficulties in sitting approvals, spatial planning uncertainties, constraints in the manufacturing supply chain and availability of installation vessels. Potential competition with other marine users. Greater financing difficulties - Advantages of offshore: higher capacity factors, higher wind speeds and lower visual impact and noise. Virtually no limit on the size of the turbines that can be installed.	- Vulnerability to cost increases due to supply shortages and higher steel prices - Negative environmental externalities (visual impact, noise, risk of bird collisions and wildlife disruption), leading to local opposition - Best places already exploited in some countries (i.e., Spain) - Additional cost burden to provide reliability, especially at high penetration rates (back-up capacity)
Solar (general)	- Large cost-reduction potential (new materials, learning effects, economies of scale). Learning rate of 15–20% [63] - Cost-competitive in some off-grid applications - Plentiful resource and low O&M costs	- High investment costs - Silicon shortages
Solar PV	- Fast-growing market - Since the electricity is fed directly into the distribution grid, its generation costs compete with electricity retail prices Positive outlook: 1) Incentive schemes in place. 2) Significant growth in the world's manufacturing capacity	(idem)
Solar CSP	- Bright prospects in sunny countries - Costs between PV and wind - Potential to deliver power on demand and continuous solar-only generation (stored heat). Good match with the peaks in electricity demand (air conditioning in Southern Europe)	- Limited availability of good-quality sunlight (only in the South of Southern Europe).
Geothermal	- Large resource and cost-reductions potentials - Reliable base-load capacity 24 h a day - Several demonstration projects of EGS currently in Europe	- Large-scale development: currently limited to tectonically active regions - Long project development times, risks and costs of exploratory drilling
Ocean (tidal and wave)	- Large unexploited resource potential for wave in the Atlantic coast - Significant progress in wave energy	- Three technology types: (1) waves and tidal and marine currents. (2) Tidal barrages. (3) Ocean thermal energy conversion, salinity gradient/osmotic energy and marine biomass: All at the demonstration stage. - Costs and reliability need to improve (especially under extreme weather conditions). Expensive pilot projects - Non-technical challenges: Environmental effects, need for resource assessment, energy-production forecasting and design tools and test and measurement standards - Sitting devices involve considerable consultation.

Source: Own elaboration from [3,7,12,24,35,57,65–69].

Finally, several studies show that the RES-E sector requires proportionally more skilled workers than other sectors [60,61]. Large increases of RES-E are expected to require retraining of existing staff, recruiting new types of employees, creating new education and reorganising the entire workforce. While this need for skills may have been a barrier in the past (see [12] regarding solar PV in Spain), it is unlikely to be so in the future. The critical mass achieved by the sector in Europe has been accompanied by a service-sector with highly qualified individuals [62]. Indeed, this factor can be a driver, given its capacity to attract young, well-educated candidates. But it can also be a bottleneck if the future of the sector is held back by the shortage of trained workers. This includes building up local innovation capacity on the back of deployment. If this is measured in terms of patents hosted in the renewable energy realm, five EU countries are among the top ten patent assignees in wind, solar PV, CSP and biomass electricity in the world.[33]

4.4. Technology-specific drivers and barriers to RES-E in the EU

A more focused list of the drivers and barriers to renewable electricity technologies in general and per technology is provided in Table 7.

[33] The rankings for wind show that U.S. is the absolute leader in patent assignments (around 2700), followed by Germany (1500), China (1000) and Denmark (600). In the solar PV realm, the U.S. (4300 patents) is followed by Germany (2400), Denmark (1000) and China (500). The U.S. is also the leader in CSP, followed by China, Germany and Denmark. In the case of biomass electricity, the U.S. is followed by China, Germany, Denmark. In each of these technologies, those countries are followed by Japan, U.K., Korea, Spain, Canada and Sweden [64].

Table 8
Assessing the drivers/barriers to RES-E in the EU in the future.

Driver/barrier		Score	Selected sources of evidence
1. Technoec. Aspects	Potentials	+ (large hydro: −)	[6]
	Evolution of fuel prices	++ (wind) + (biomass) +/0 (solar PV) 0 (immature)	[17]
	Investment cost	++ (mature) + (high-cost commercial) − (immature)	[3,17,18,20,26,28]
	Investment cost trends (learning effects)	++ (offshore wind and biomass gasification) + (wind on-shore)	[18,28,31]
	Age of plants	− (mature), mitigated as 2030 approaches + (window of opportunity for the least mature)	[7,17,20,33,34]
	Grid integration	−− (wind) − (solar)	[12,35,37,38,53]
2. Policies	EU ETS	+ (mature) 0 (immature and high-cost commercial)	Simulation studies in Section 3 [29]
	Deployment policies (FITs)	++	[30,36,40]
	R&D support	0 (mature) ++ (immature) + (high-cost commercial)	[26]
3. Other factors	Electricity market liberalisation process	− (mature) 0 (immature) (direction of effect is arguable).	[7,20]
	Administrative procedures	− (clearly in the short-term)	[31]
	Public acceptability (general)	+	[55,56]
	Public acceptability (local, NIMBY)	− (on-shore wind)	[56–59]
	Skills	0 (unlikely to be a barrier except for specific technologies/countries)	[62]

Source: Own elaboration (see text). (++) strong driver; (+) important driver; (0) uncertain direction of effect; (−) important barrier; (−−) strong barrier.

Table 8 summarises the above qualitative assessment of different barriers and drivers to RES-E in the EU.

5. Discussing expected trends of RES-E in the EU

This section provides an assessment of likely trends per renewable energy technology in the period, considering the model results (Section 3) and the drivers and barriers discussed in Section 4.

- *Biomass* will grow significantly in the period, although behind other renewables (except hydro), due to the existence of RES-E support schemes, the targets of the new renewables directive and political justification for support given its climate and non-climate change benefits, even in the absence of a strong climate policy. Investment costs are expected to be reduced substantially. Higher fuel and carbon prices add another incentive, but non-price barriers should be removed (logistics. . .).
- *Hydro. A* constant share during the period can be expected under a baseline scenario,[34] with a small increase in absolute terms. This is due to limited resource potentials, social rejection to new dam construction and investment costs unlikely to be reduced.[35] Higher carbon prices are unlikely to make this technology much more attractive, given these barriers [1].
- *Wind* will significantly increase in absolute terms, stimulated by significant investment cost reductions due to learning economies, increasing fuel prices, the continuation of promotion schemes, unexploited potential (especially for wind off-shore), the existence of a large and booming industry in Europe, improved resource prediction methods for grid integration, better grid management and increased inter-country connections. The relatively low share of wind in total generation (between 5% and 7% in 2030) would not involve great challenges to the stability of the grid, which could be a barrier with much higher percentages (i.e., 30% and above). Higher carbon prices would also provide an additional boost to this technology (under a policy scenario). Security of supply concerns, other local socioeconomic and environmental benefits and intense lobbying effort by the coalition of forces benefiting from wind make the continuation of promotion schemes likely. In contrast, increases in the price of materials (steel), potential NIMBY effects and grid integration issues with higher penetration levels may limit its growth. Nevertheless, the possibility that decreasing returns play a role when approaching 2030 cannot be discarded [1]. Once the best locations have been occupied, the next ones will induce higher costs.
- *Solar*. A substantial absolute increase can be expected, due to generous promotion policies in some countries (i.e., Spain and Germany), increasing fuel prices, large unexploited resource potentials and significant investment cost-reductions. However, solar would generally not be cost-effective during the period. Other obstacles are: required back-up capacity and grid integration. Higher carbon prices may not provide a significant incentive, given its high cost differentials with other sources.[36] Nevertheless, more stringent CO_2 targets could make the adoption of more aggressive PV support policies more likely.
- Regarding *other RES* (ocean and geothermal), these can be expected to increase during the period, although from a close-to-cero base. Their share will be negligible during the period given their non-maturity and/or high relative (investment) costs. Higher carbon prices and the intensification of other policies

[34] This includes already implemented climate policy which will continue in the future like the EU ETS.

[35] Indeed, according to [17], learning rates for hydro are expected to be negative (−0.5% per year for large hydro and −1.2% per year for small hydro). See Section 4.

[36] In the *policy scenario*, one study expects a higher deployment with respect to the baseline (WEO2007) and another a similar level of deployment (REMIND).

(R&D, demonstration, support schemes for deployment) are unlikely to lead to significant shares of these technologies.

Whereas hydro is stagnant, wind and solar show a clear upward trend. Finally, the trend of biomass and other RES are especially uncertain during the period because they depend on non-price barriers being removed and the extent of technological improvements, which are particularly difficult to foretell.

6. Concluding remarks

This paper has discussed the main drivers and barriers to RES-E in the EU, with a differentiation per technology. While simulation models provide some insights, they cannot grasp the whole complexity and challenges involved in large-scale deployment of RES-E that the models envisaged as necessary in a low-carbon context.

Regarding the most mature renewable electricity technologies (wind on-shore), the main drivers will be public policies (carbon prices and deployment support) and the expected up-ward trend in fossil-fuel prices and the main barriers are related to grid access, administrative procedures and the exhaustion of places with the best wind resource. For those already commercial but expensive technologies (solar PV), the main driver is deployment schemes, but not carbon prices, allowing the exploitation of the large potential for investment cost reductions. Barriers are mostly related to their high investment costs. Finally, for those technologies which are emerging and immature (i.e., EGS), further technical improvements as a result of R&D efforts will be needed and they cannot be expected to significantly penetrate the European electricity market until 2030. Therefore, carbon prices will continue to be combined with technology-specific policies (in the form of deployment support and direct support for R&D and demonstration).

Support will have to be stable and granted at moderate costs if it is to be socially acceptable and politically feasible. In addition, non-price barriers (notably grid access and administrative procedures) will need to be removed. In particular, flexible power market design integrating energy, transmission and balancing markets and the demand side and tailored network expansion will be crucial elements for RES-E penetration [1]. If public acceptance becomes an issue with greater RES-E penetration levels, information campaigns should be implemented to increase public awareness on the advantages of these technologies.

What are the implications for the European dimension of support? Some authors argue that cost-effectiveness in meeting the EU target of 20% of renewable energy requires that RES-E is physically produced where it is cheapest and, thus, support should encourage this. The RES Directive allows some trading of renewables, which goes in this direction. However, as countries are willing to keep control of their support schemes, a harmonised support scheme for RES-E cannot be envisaged in the medium term. Coordination and cooperation between countries may de-facto lead to convergence within support schemes, as it has been the case with FITs.[37]

Regarding R&D efforts, support should be better structured at supranational levels, through, for example, tax credits, research grants and direct support for demonstration projects, given that its benefits are likely to spill to different countries. The existence of this technological externality reduces the incentive for single countries to publicly invest in R&D, leading to suboptimal levels of investments. There is thus a clear case for promoting efforts in this direction at the EU level (in the line of the CCS Directive) or, at least, for coordination of Member States' efforts.

[37] See [36]. Germany, Spain and Slovenia have set up the joint project International Feed-In Cooperation (http://www.feed-in-cooperation.org/).

Finally, it is important that Europe does not lose the global race in the renewable energy market. These technologies hold the promise of socioeconomic and environmental benefits in the short, medium and long-run. Grasping the opportunities offered by this highly dynamic market on a wide-array of renewable technologies depends on EU-level and Member State action on several fronts (support schemes for R&D, demonstration and deployment, planning, setting of visions), as outlined in the SET Plan [41].

Acknowledgements

Financial support from CSIC (proyecto intramural) and from Allianz and WWF (RECIPE project) is gratefully acknowledged.

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